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RESEARCH ARTICLE

An assessment of the factors determining rotifer assemblage in river-lake systems: the effects of seasonality and habitat

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ABSTRACT. Zooplankton exhibit several trends of variation in space and time, and these trends can be more evident in natural environments without anthropic perturbations. Examples of anthropic factors are climate change, eutrophication and construction of reservoirs. This study evaluated the influence of three factors – seasonality, type of environment and the presence of aquatic macrophytes – on various ecological attributes of rotifers in a river-lake system located in the Paraná River floodplain. Monthly samplings were conducted during 1993 and 1994. The mean species richness per sample was 60 species. The seasonality and the type of environment influenced the ecological attributes of rotifer assemblages, while the presence or absence of aquatic macrophytes did not. Species richness was highest in the lake system and during the months when water levels were low. Multivariate analysis indicates a small group of species associated with the low water-level phase. In contrast, many species were associated with high water levels or increasing water levels. The seasonal variation of hydrological cycle and the type of environment are the most important factors for rotifer structure in natural conditions.

KEY WORDS. Ecology, limnology, Rotifera, Upper Paraná River floodplain.

INTRODUCTION

Floodplains include complex aquatic habitats and ecotones in the context of terrestrial environments (Junk and Welcomme 1990). They are heterogeneous landscapes that harbor high biodiversity due in large part to changes in hydrometric levels or "flood pulses" (Thomaz et al. 2009).

Flood pulses is one of the major factors responsible for periodic changes in the composition and abundance of zooplankton and other fauna (Lansac-Tôha et al. 2003, 2004, 2009, Velho et al. 2001, Serafim-Júnior et al. 2003, Aoyagui and Bonecker 2004, Bonecker et al. 2009).

Connectivity between different floodplain environments, including rivers, canals and lakes can determine distinct types of communities, while their abundance is influenced by limnological variables and biotic interactions such as competition and predation (Ward and Stanford 1995, Thomaz et al. 2004, Azevedo and Bonecker 2003).

River-lake floodplain systems are highly productive due to the periodicity of nutrient input in the form of dissolved and particulate matter, derived from the lateral exchange between water and terrestrial habitats when the water is high (Junk and Welcomme 1990, Thomaz et al. 2004). This seasonal characteristic results in temporal patterns according to hydrometric levels and fluviometric fluctuations. Generally, species richness and abundance of aquatic communities are low when water levels are high, as a result of dilution, and higher when the water level is low (Casanova and Henry 2004).

Rotifers are a species-rich group of zooplankton. They are present in various environments within a floodplain owing to their substantial capacity for colonization (Serafim-Júnior et al. 2003, Lansac-Tôha et al. 2009). Planktonic organisms tend to

be more abundant in lentic systems such as lakes compared to lotic systems such as rivers, most likely as a result of water flow (Perbiche-Neves et al. 2012, Portinho et al. 2016).

In fact, lakes and rivers differ in several other variables such as turbidity, transparency, temperature, chlorophyll, nutrients, and suspended matter (Perbiche-Neves et al. 2014). The abundance of rotifers tends to be higher in the pelagic (lacustrine) zone compared to the littoral zone (Perbiche-Neves et al. 2014). Their feeding habits vary depending on their environments, with many pelagic species filtering small organisms and littoral species usually collecting detritus and periphyton (Bonecker and Lansac-Tôha 1996, Lansac-Tôha et al. 2003, Aoyagui and Bonecker 2004).

The abundance and richness of rotifers floodplain lakes are dependent on the presence or absence of aquatic macrophytes (Duggan et al. 2001, Kuczynska-Kippen and Nagengast 2006, Colares et al. 2013). Usually, there are fewer taxa in the pelagic zone without macrophytes, and more taxa when macrophytes are present, with around 20% of the taxa being exclusive to regions that have aquatic macrophytes. Macrophytes provide a fundamental element in the trophic chain by offering a variety of microhabitats used as refuges against visual predators and as reproductive sites for different taxa (Velho et al. 2001, Lansac-Tôha et al. 2004). Distinct species of macrophytes can promote the development of specific rotifer assemblages associated with the architecture of the habitat and the spatial distribution of these plants (Duggan et al. 2001, Kuczynska-Kippen and Nagengast 2003, Choi et al. 2015).

The aim of this study was to detect differences in the ecological attributes of rotifers in a river-lake environment in the floodplain of the Upper Paraná River, comparing the effects of seasonal variation, types of environments and the presence or absence of aquatic macrophytes. Based on the literature, the hypothesis tested was that aquatic macrophytes are the main cause of differences in the ecological attributes of rotifers.

MATERIAL AND METHODS

The environments connected to the Paraná River are associated with naturally high-water transparency and low concentrations of phosphorus. The water quality of the surrounding lakes differs depending on the hydrometric levels of the river and the level of connection between the habitats. Further limnological details on the variations of this region can be found in Thomaz et al. (2004) and Roberto et al. (2009).

This study analyzed a section of the Ivinhema River, which is one of the main tributaries of the right side of the Paraná River inserted in the Paraná River floodplain. We sampled three sites in the river stretch (22°50'S, 53°34'W) characterized by turbulent and shallow waters. Six sampling sites were also established in the Patos Lake (22° 49'S, 53°33'W), located on the left side of the Ivinhema River, connecting with the river channel throughout the seasonal cycle in flood pulse (Fig. 1).

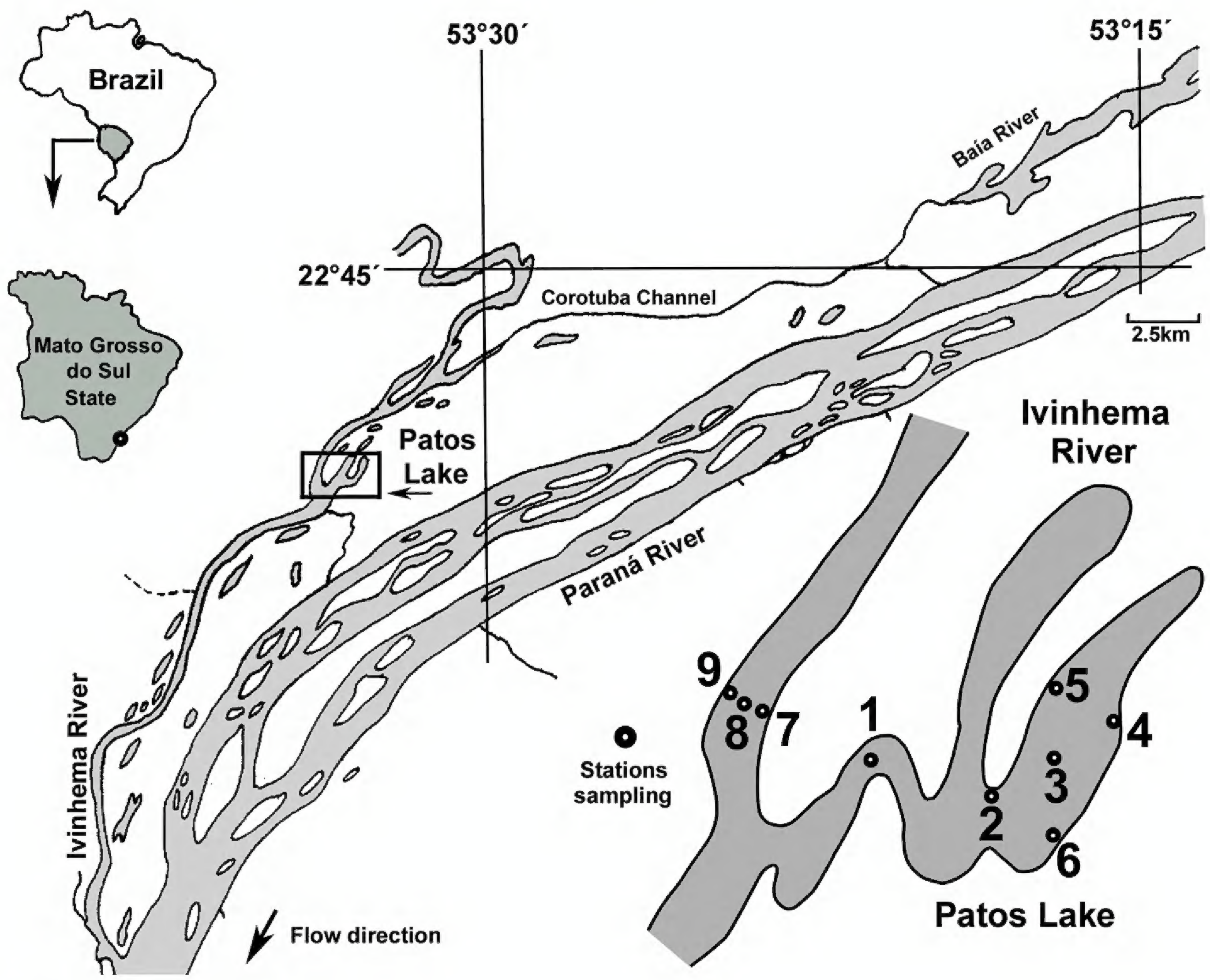

Figure 1. Sampling area and sampling sites.

The marginal vegetation in the sampling sites at the river and lake included trees, shrubs, grasses (*Panicum* sp.) and stands of aquatic macrophytes. The most common species were: *Eichhornia azurea* (Sw.) Kunth, *E. crassipes* (Mart.) Solms, *Salvinia biloba* Raddi, *S. auriculata* Aubl., *Pistia stratoides* L., *Polygonum ferrugineum* Wedd., *Utricularia foliosa* L., and *Oxycaryum cubense* (Poepp. & Kunth) Lye. Bini et al. (2001) and Thomaz et al. (2004, 2009) provided more detailed information about the community of aquatic macrophytes in the floodplain of the Upper Paraná River.

We obtained monthly samples between March 1993 and February 1994 at nine sampling sites: three located on the Ivinhema River (two on the stands – site 9 and site 7; and one in the middle of the river channel – site 8); one on the connecting channel between the lake and the river (site 1); and five distributed within the lake (sites 2–6), alternating between pelagic and littoral sites (Fig. 1 and Table 1). A total of 108 samples were obtained and deposited in the collection of zooplankton samples (ZPK) of the Núcleo de Pesquisas em Limnologia, Ictiologia e Aquicultura (NUPELIA-UEM).

Table 1. Sampling sites, type of environment and composition of the marginal vegetation.

Sites	Environment	Macrophytes
1	Pelagic/channel	–
2	Littoral/lake	*Eichhornia azurea*
3	Pelagic/lake	–
4	Littoral/lake	*Panicum* sp.
5	Littoral/lake	*Polygonum* sp./*E. azurea*
6	Littoral/lake	*Polygonum* sp./*E. azurea*
7	Littoral/river	*E. azurea*/*Polygonum* sp./*E. crassipes*
8	Pelagic/river	–
9	Littoral/river	arborous/arbustive

Zooplankton samples were taken at each site using a conical plankton net with a mesh size of 68 µm. We filtered 1,000 liters of subsurface water per sample using a motor-pump. The samples were fixed with a solution of sucrose and formaldehyde 4% and buffered with calcium carbonate.

Rotifers were identified at the species level based on several studies: Koste (1978a, b), José de Paggi (1995), Koste and Robertson (1983), Nogrady et al. (1993) and Segers (1995). Zooplankton was counted using a Stempell-type pipette in Sedgwick-Rafter chambers under optical and stereoscopic microscopes. At least 200 rotifers (individuals) were counted per sample with final densities expressed in individuals per m^3. Samples with low densities were thoroughly analyzed.

Taxon occurrence in lacustrine and littoral regions were reported. Rotifers community structure were assessed using species richness, total abundance, Shannon Wiener diversity index, and evenness (Magurran 2004). These response variables were compared to verify the influence of the three aforementioned factors: months (seasonality), the type of environment (river or lake), and aquatic macrophytes (present or absent).

A non-metric multidimensional analysis (NMDS) was used to explore the data obtained on abundance, aiming to detect differences between the factors studied. The ordination used a Bray-Curtis dissimilarity matrix, after data was transformed logX+1. All statistical analyses were performed using function in the packages vegan and MASS (Ripley et al. 2018) for R (Oksanen et al. 2018) of the free software R Cran Project 3.5.1 (R Development Core Team 2016).

RESULTS

The hydrometric level showed three peaks along the studied annual cycle (Fig. 2). The study recorded the highest hydrometric levels of the Ivinhema River in the austral autumn and winter seasons, between March and June 1993, and in the summer, during February 1994. The lowest water level occurred from August to December 1993 and January 1994. The level of the lake varied drastically for short periods, for example there were high fluctuations when the months of May, April and June of 1993 were compared (Fig. 2).

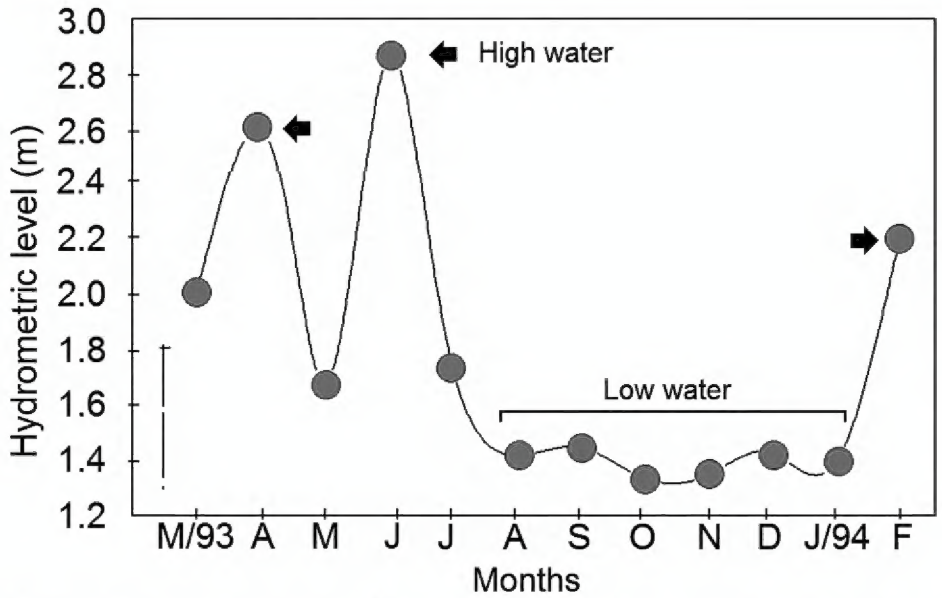

Figure 2. Hydrometric levels represented by means of thirteen days before the samplings (Thomaz et al. 2004), between March/93 to February/94 in the Ivinhema River.

The 179 species found belonged to 24 families, with Lecanidae, Brachionidae and Trichocercidae, showing the highest numbers of taxa. The list of species found in our study is presented in the supplementary file Table S1. The mean value of species richness (S) was 60 (CV = 26.6%), while the lowest value (23 species) was observed in one of the stands of the lake colonized by *Polygonum* sp. and *E. azurea* (site 6) in August/1993. The highest species richness (99) was found in another section of the lake colonized by *E. azurea* (site 2) in November/1993.

In terms of months (Figs 3, 4), low values of richness and diversity were found between July and September, during low hydrometric levels of the Ivinhema River. With respect to abundance, the lowest value was observed in March and June, contrasting with other ecological attributes, though it is

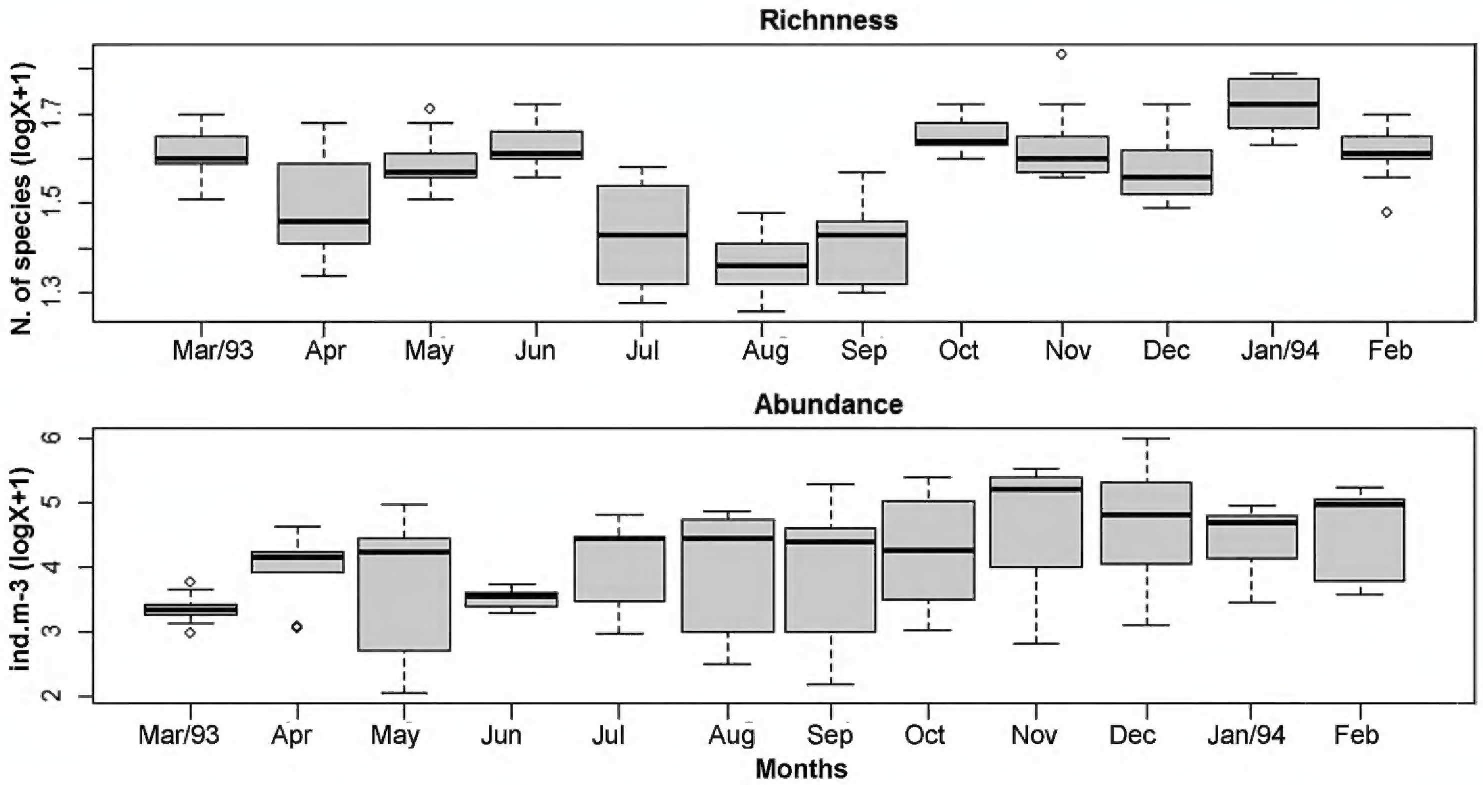

Figure 3. Mean values of richness and total abundance among the sampling months.

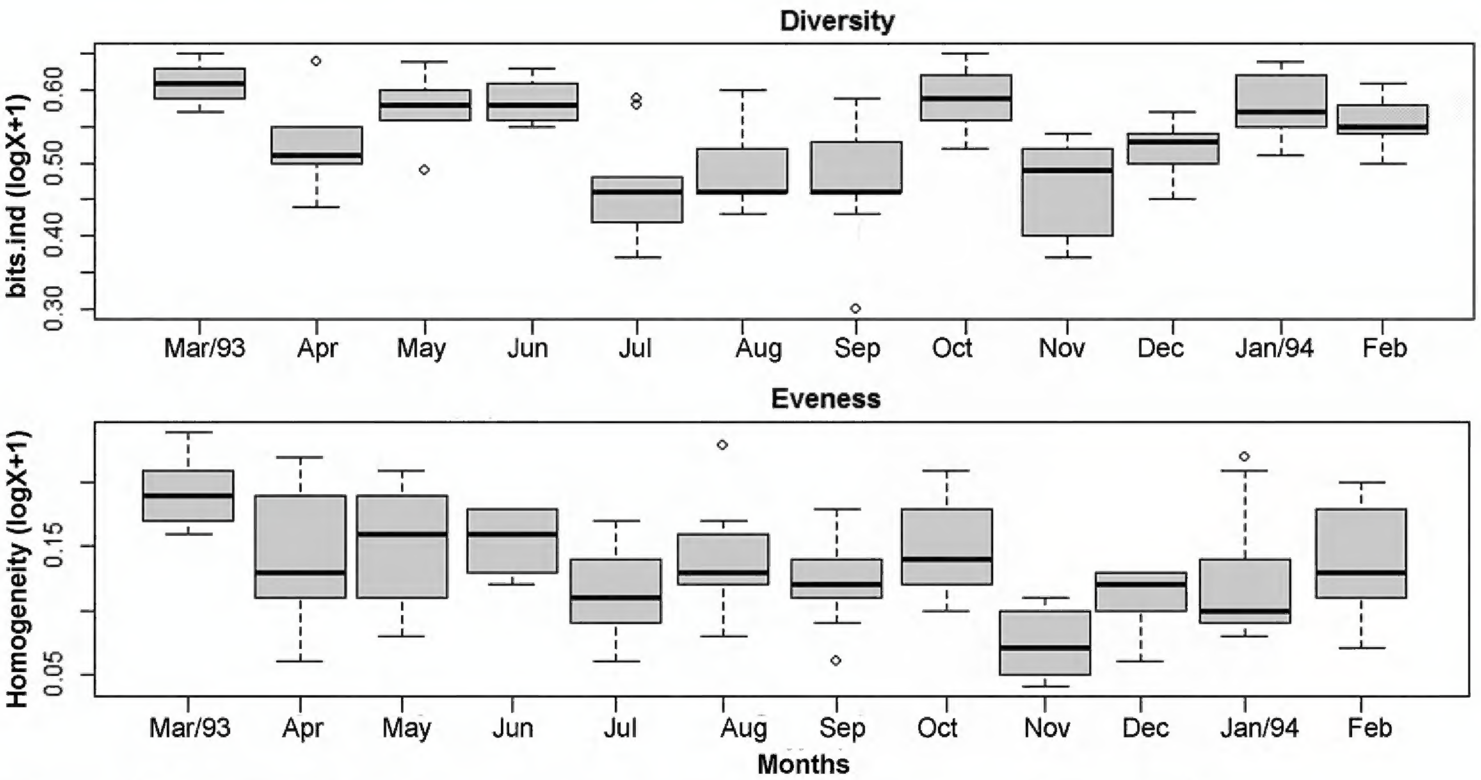

Figure 4. Mean values of Shannon-Wienner index diversity and eveness among the sampling months.

important to note that there was a peak in hydrometric levels, only observed during June.

Pertaining the Shannon-Wiener diversity index, the months were separated into two groups: April, July, August, September, November and December with low values of diversity, and March, May, June, October, January and February with high values, being also associated with low and high levels of water, respectively. For evenness, July, November and January, both with low levels, had low values compared to the other months, while March exhibited the highest value.

Comparing results across sampling sites (Fig. 5), the abundance was low in the Ivinhema River at sites 7, 8, and 9, while diversity and evenness were high. Abundance was also high in the lake environment, although diversity and evenness metrics were lower compared to the river.

The NMDS analysis (Fig. 6) based on an abundance matrix separated rotifer species according to the low and high-water levels, showing groups of species for each phase and conversely some species were not associated with any period, in the middle of the biplot of Fig. 6. The effects of environment type and the presence of macrophytes were not visible.

Conochilus unicornis (Cuni), *Pitgura* sp. 3 (Ptsp3), *Pleosoma truncata* (Ptru), *Polyarthra dolychoptera* (Pdol), *Trichocerca similis* (Trsc), *Colurella* sp. (Cosp1), *Trichocerca scipio* (Trsi), *Brachionus calicyflorus* (Bcal), *Keratella cochlearis* (Kcoc), *Brachionus reductus* (Bred), *Brachionus dolabratus*, among others at the positive val-

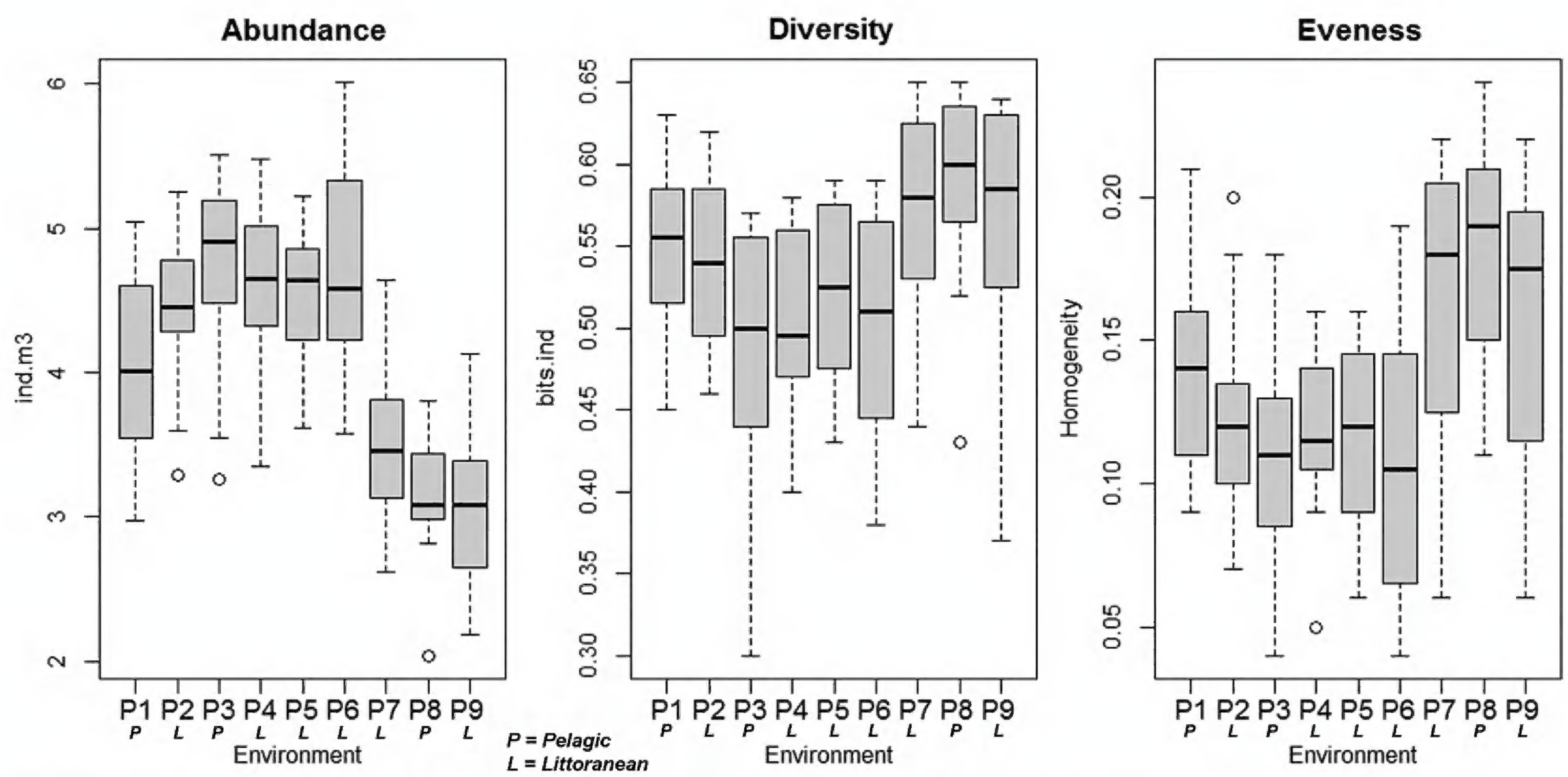

Figure 5. Comparison of mean values of total abundance, Shannon-Wiener diversity and evenness among the sampling sites.

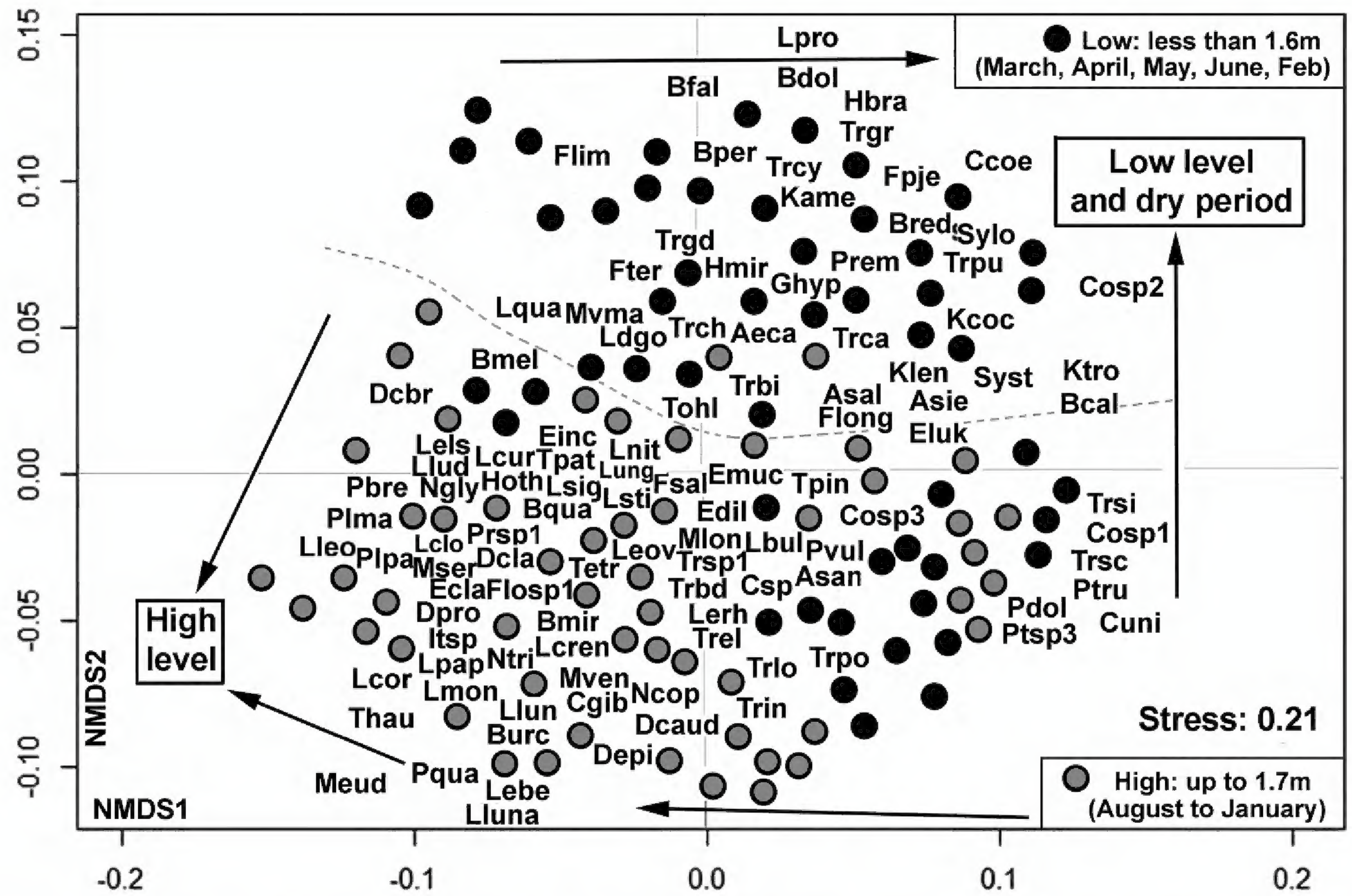

Figure 6. Biplot of NMDS analysis used to explore spatial-temporally the rotifers assemblage, based in an abundance matrix. For codes of species see supplementary file Table S1.

ues in the biblopt, are examples associated with low levels. In contrast, there was another group associated with high water level, for example *Lecane cornuta* (Lcor), *Lecane monostyla* (Lmon), *Brachionus urceolaris* (Burc), *Dicranophorus epicharis* (Depi), etc.

DISCUSSION

Of the three factors studied, the hydrological phases, months and the environment type were important factors in the ecological structure of rotifers. The presence or absence of aquatic macrophytes was not important in our study, contrasting with several other studies that pointed to the importance of macrophytes to provide food resources and refuge against zooplankton predators (Bonecker and Lansac-Tôha 1996, Lansac-Tôha et al. 2004). Thus, we reject the hypothesis tested.

The analysis showed that there were clear differences in the species assemblages between low and high-water levels in the system rive-lake. The effects of the hydrological phases and their

seasonal variation on the zooplankton is well documented in many floodplains systems, and previous authors have mentioned variations in hydrometric levels (Espindola et al. 1996, Lansac-Tôha et al. 2009, Bonecker et al. 2009). Besides the cyclical periods of high and low water levels, sometimes there are rapid changes in the level of the water, as observed in April and May. Hydrometric fluctuations can occur within a brief period, with weekly or even daily intervals in both phases of the hydrological regime (Thomaz et al. 2004). The hydrometric level is the factor that best explains the spatial and temporal heterogeneity of several limnological parameters of lentic, semi-lotic and lotic subsystems in this floodplain (Thomaz et al. 2004), and these variables tend to control an important part of the zooplankton community (Lansac-Tôha et al. 2009, Dias et al. 2016).

The richness and Shannon-Wiener diversity index were higher in the high-water levels and also for a period of time following the reduction of the level, suggesting that the stabilization of water levels in the river and lake correlates with high richness and diversity, with a similar phenomenon occurring after a great peak in water levels. This peak can be attributed to a disturbance that generally induces variations in richness and diversity (Serafim-Júnior et al. 2016).

Low values of rotifer densities when the water is high is common in river-floodplain systems, as observed here in June because of the dilution of organisms. In contrast, the highest densities were found during the low water period, which could be attributed to the effect of concentration (Lansac-Tôha et al. 1993, Espindola et al. 1996, Rossa and Bonecker 2003, Bonecker et al. 2009). Lower densities in the high-water period is partly attributed to the dispersion of zooplankton in the lakes by advective transport, caused by the flow of water that is established in these environments during the flood and in the river's own water flow (Casanova and Henry 2004).

The multivariate analyses in our study associated a group of taxa with low-level water months, and another group of species was observed in high-level, with similar dominance. In lotic environments, littoral and pelagic taxa can co-exist. The proximity between the littoral and pelagic regions along with the daily mixing of the water column in the studied area favor the occurrence of many species, and typically littoral species are caught in the pelagic compartment (Lansac-Tôha et al. 2003, Bonecker and Lansac-Tôha 1996, Velho et al. 2001, Bonecker et al. 2005, 2009). Moreover, during the flood pulse, many aquatic macrophytes are carried by the flowing water to open-waters (Aoyagui and Bonecker 2004).

Water flow is one of the main environmental factors responsible for the presence and abundance of zooplankton in lotic environments (Paggi and José de Paggi 1990). Comparing river, channel, and lake environments, the highest zooplankton densities were observed in the lake and the highest diversity and species richness in the river (Perbiche-Neves et al. 2014), as verified in the comparative analysis.

Changes in populations should result from recruitment and loss processes between the boundaries of the lake or the hydraulic washout transport associated with the flood events (Hamilton et al. 1990). However, if the residence time of the water is less than the generation time of organisms, there will be no time remaining for the population of a species to increase in abundance. In the lakes of central Amazonia, the density of zooplankton decreases about three times with respect to the ebb period during periods of flood (Hardy 1980). On the other hand, the higher density values in the low water phase can be attributed to the concentration of the water mass and reduction of the water level at the lake. The reduction of the flow velocity, which is high in the full phases, and the addition of the input of nutrients and organic matter from the margins also contribute to these values (Espíndola et al. 1996, Lansac-Tôha et al. 2004, Bonecker et al. 2002).

Our study concludes that temporal variations and the type of environment were more important to rotifer structure than the presence or absence of aquatic macrophytes. Within a year of sampling and several sampling sites, we were able to identify the effects of natural hydrographic water levels on the ecological attributes, impacting the effects of dilution and concentration on these organisms. As expected, lotic waters were not favorable to the abundance of organisms though they harbored increased species richness and diversity.

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